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STUDY OF THE PLASMA OF WATER STABILIZED PLASMA GENERATOR-SPECTROSCOPIC MEASUREMENTS OF TEMPERATURES[1]

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The free flow plasma of the water stabilized plasma generator (Czechoslovak type PAL 160) was studied. Emission spectral lines H_β, FeII and bands of OH were used. The measured temperatures are in the range from 4000 to 16000 K.

I. INTRODUCTION

Plasma generators are widely used in industry (see for instance [1]). Czechoslovak plasma generators are used especially for large scale spraying of ceramics materials (Al_2O_3, $Al_2O_3 + TiO_2$, $ZrSiO_4$ etc.). The working fluid is water, the surface of which creates the arc-stabilizing walls. The arc burns between a consumable carbon cathode and a rotating steel anode (see Fig. 1). Water plasma flows with the velocity of the order 1000 m/s from the nozzle. Into the free flowing plasma there is fed powder, which is melted and accelerted onto the substrate surface where it creates the layer.

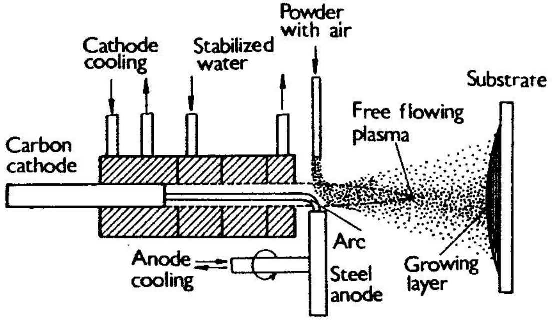

Fig. 1. Scheme of water stabilised plasmatron.

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In the arc burning in water plasma one can achieve temperatures up to 55 000 K [2]. The temperature in the arc can be determined from the relative and the absolute intensities of hydrogen (Balmer series) and oxygen O II lines, from the ratio of hydrogen line intensities to the continuum and from the shape of the hydrogen lines [3].

II. EXPERIMENT

We used the Czechoslovak water stabilized plasma generator PAL 160 with the rated power input 160 kW. The efficiency of the electrical energy transfer into the plasma was measured calorimetrically from the heat losses in the water cooled anode and cathode and in the working fluid. It achieved values of up to 70 % at the power input 170 kW (current 510 A, voltage 330 V, diameter of stabilizing channel 12.5 ÷ 6 mm, diameter of the outlet nozzle 6 mm) [4]. The generator was installed on a stand with the possibility of horizontal motion.

Emission optical spectra from free flowing plasma were taken in the radial direction by the spectrograph Q 24 on the photoplates ORWO WU 1 ÷ 3 at different distances *l* from the outlet nozzle. The spectra were processed by the microdensitometer MD 100. Wavelengths were calibrated by hydrogen and Fe II lines. No absolute intensity calibration was made. No Abel transformation was used and the resultant values of temperature are the mean or effective ones.

III. TEMPERATURE MEASUREMENTS

a) Atomic spectra

The spectra taken from the vicinity of the nozzle contain atomic lines of hydrogen (Balmer series), O II from the stabilized fluid matter and C II which originates from the cathode material. At the distance of 10 mm from the nozzle there was observed an intensive emission of Fe II lines originating from the steel anode. The observed lines O II and C II were not suitable for temperature determination from the pyrometric line.

The most intensive line in the spectra was the hydrogen line H_β. Its halfwidth achieved values of up to about 6 nm, which documented a high density of charged particles. The asymmetry of this line (see Fig. 2) was caused by the quadratic Stark effect [5] and by the existence of the intensive and wide line H_γ [3]. Because of troubles with the halfwidth determination of H_β a very simple method of electron density determination from the distance of two maxima (as in [6]) was used. Theoretical values for a maxima distance were taken from [7]. If we assume the local thermodynamic equilibrium in the core of the flowing plasma, we can determine its temperature. The results of calculation of the water plasma composition were taken from [2]. These are in the Table 1. The error of this method is up 15 ÷ 20 %.

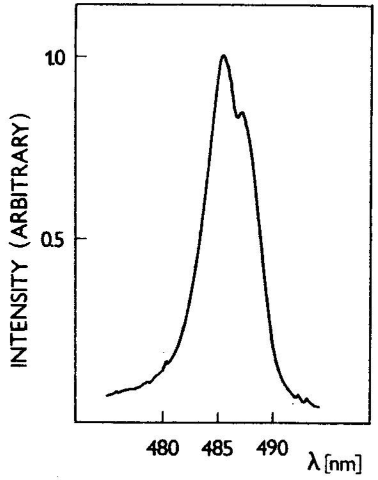

Fig. 2. The shape of the H_β-line.

Table 1

Temperature determined from the shape of the H_β-line (T_H), from the Fe II-lines (T_{Fe}), from the shape of the OH (0,0) band (T_{OH}) and from the lines of the branch R_{22} of the OH (0,0) band ($^2T_{OH}$).

l [mm] T [K]	10	19	28	37	45	65	77	89
T_H	16 000	15 300	15 000	13 300	12 900	—	—	—
T_{Fe}	6 680	6 470	5 100	4 900	4 500	—	—	—
$^1T_{OH}$	—	—	—	—	—	4 400	4 070	4 010
$^2T_{OH}$	—	—	—	—	—	4 570	4 070	3 490

The surface of the steel anode is partially melted and evaporated. From the observed Fe II (see Fig. 3) lines excitation temperatures were determined by means of the pyrometric method. The procedure was repeated for different distances from the nozzle (see Tab. 1). The oscillator strength was taken from [8]. The mean deviation of measurements was up to 6 %.

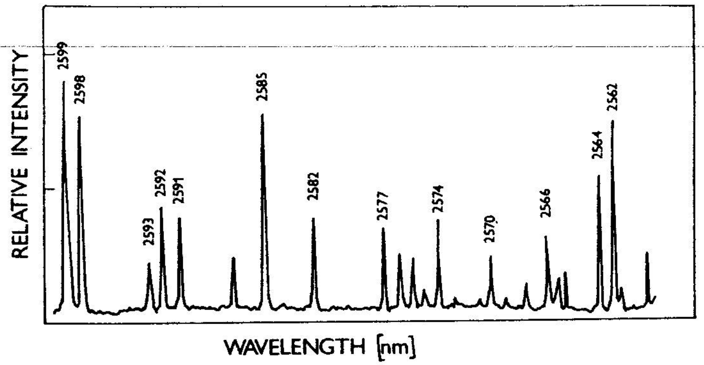

Fig. 3. A part of the spectrum employed for the computation of Fe II excitation temperatures.

b) Molecular spectra

The vibrational bands of the transition $A^2\Sigma \rightarrow X^2\Pi$ of OH for distances $l \geqq 28$ mm were identified. The spectrograph Q 24 has a relatively low dispersion (1.35 nm/mm) in this region and therefore the obtained molecular spectra were only partially resolved.

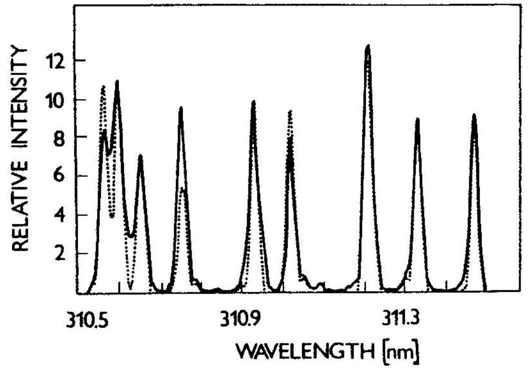

Fig. 4. An example of a part of OH spectra, theoretical (– – –) and experimental (———), used for rotational temperatures determination.

Two methods for rotational temperature determination were used. The first method is based on a comparison of normalized synthetic and experimental profiles of the vibrational band. In our case we chose the region from 309.8 to 312.2 nm of the band OH (0,0), where the overlapping of other vibrational bands is negligible. The theoretical band shape was calculated using the rotational line shape described by Phillips [9] and the line parameters for the OH (0,0) band published by Goldman and Gillis [10]. The first estimated spectral resolution ($W = 0.025$ nm) was determined more precisely during the least square fitting ($W = 0.022$ nm). The best theoretical accuracy of rotational temperature determined by this procedure is about ± 30 K [9] [11] and in our case dropped owning to the photoplate nonlinearity. A part of the experimental ($l = 45$ mm) and the corresponding theoretical ($T = 4010$ K) spectra is given in Fig. 4.

The second method employs a better resolution of the rotational lines of the branch R_{22} of the OH (0,0) band. We used the simplified method described by Dieke and Crosswhite [12]. The principle lies in searching just two lines of a comparable intensity with a low and a high N-value (angular momentum without electronic spin) of the same branch. From the theoretical intensity distribution in the branch we determine the rotational temperature. This method is independent of plate calibration. Furthermore, the effect of self-absorption is negligible in the first order approximation, as lines with the same intensity are affected to this approximation in the same way as by self-absorption. In our case only the lines $R_{22}(N = 1)$, $R_{22}(3)$, $R_{22}(4)$, $R_{22}(14)$, $R_{22}(15)$, $R_{22}(20)$, $R_{22}(23)$ could be sufficiently resolved.

The result of the measurements in both cases are presented in Tab. 1.

IV. DISCUSSION — CONCLUSION

From considerably different temperatures determined from the H_β line and from the Fe II lines we can conclude that in the interval of distances $l = 10 \div 45$ mm from the nozzle no mixing of the plasma core with the surrounding gas containing Fe vapours takes place. If this laminar core of the flowing plasma is sufficiently long, the particles can obtain a high velocity and if they are sufficiently melted, the coating becomes highly adhesive.

The rotational temperatures determined by both methods are in good agreement. If we assume that the free flowing plasma is near LTE [13], the rotational temperatures are equal to the translational ones. We can see that even at a relatively great distance from the nozzle (90 mm) the temperature is sufficiently high to melt ceramic particles such as Al_2O_3.

A further study is intended on an improvement of spectra modelling and on a spatial resolution of temperatures by means of the Abel transformation.

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ИЗУЧЕНИЕ ПЛАЗМЫ ВОДОЙ СТАБИЛИЗИРОВАННОГО ПЛАЗМЕННОГО ГЕНЕРАТОРА — СПЕКТРОСКОПИЧЕСКОЕ ИЗМЕРЕНИЕ ТЕМПЕРАТУР

В работе изучается свободный поток плазмы водой стабилизированного плазменного генератора (чехословацкого производства PAL 160). Были использованы спектральные линии излучения H_β, Fe II и полосы OH. Измеряемые температуры находятся в интервале от 4000 до 16 000 K.